Measurement of Hyperion MTF from on-orbit scenes

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ABSTRACT

The Hyperion instrument was launched November 21, 2000 mounted on the EO-1 spacecraft into orbit 1 minute behind Landsat-7. Hyperion has a 7.5 km swath width, a 30 meter ground sample distance (GSD) and more than 220 spectral bands. Part of the on-orbit characterization involves MTF measurements from several ground scenes. These scenes included edges from the moon and glaciers as well as several bridges. The scenes were processed to determine the MTF for both the Visual Near InfraRed (VNIR) and Short-wave InfraRed (SWIR) imaging spectrometers and were compared to measurements made prior to launch.

Keywords: Hyperspectral Imaging, MTF, Hyperion, EO-1, spotlight, Landsat-7

1. INTRODUCTION

The MTF is a measure of spatial resolution for an imaging system. On-orbit imaging system MTF has been determined from imagery of bridges[1, 2]. The edge technique for measuring MTF is described[3] and has been demonstrated in the lab[4] and is utilized to measure MTF from on-orbit scenes. The edge method develops the Edge Spread Function (ESF) by interlacing multiple adjacent scans from an object that is at a slight angle to the satellite direction. The Line Spread Function (LSF) is determined with two methods: a curve-fit technique and a band-limited derivative. The MTF is obtained by processing the LSF with the Fourier transform. The bridge method develops the LSF directly from multiple adjacent scans similar to the edge method. The LSF is then processed with the Fourier transform and adjusted by the bridge width to obtain the MTF.

2. HYPERION MTF REQUIREMENT

The MTF requirement is dependent on the wavelength as shown in Table 1. The requirement is specified at the Nyquist frequency.

Table 1: Hyperion MTF Requirement

	VNIR MTF			SWIR MTF			
λ (μm)	0.45	0.63	0.90	1.05	1.25	1.65	2.20
MTF Requirement	0.20	0.20	0.15	0.14	0.14	0.15	0.15

The measured in-track MTF is shown in Table 2. The in-track MTF is calculated from the measured cross-track MTF by multiplying by $2/\pi$ which adjusts for the MTF degradation due to spacecraft motion.

Table 2: Pre-Flight Measured MTF

λ (μm)	FOV > 200	Center FOV	FOV < 20
0.5	0.29	0.27	0.22
0.63	0.27	0.28	0.22
0.90	0.24	0.26	0.22
1.05	0.28	0.3	0.28
1.25	0.28	0.3	0.27
1.65	0.27	0.27	0.25
2.2	0.28	0.27	0.23

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3. MTF EXAMPLES

3.1 Edge Method using Ross Ice Shelf

The image of the Ross Ice Shelf (Fig. 1) was acquired on January 16, 2001. This Hyperion image is from band 28 (λ = 630 nm). This image was used to determine the in-track MTF. The edge angle is larger than desired which results in a calculated MTF reduction but this effect can be removed from the final MTF result.

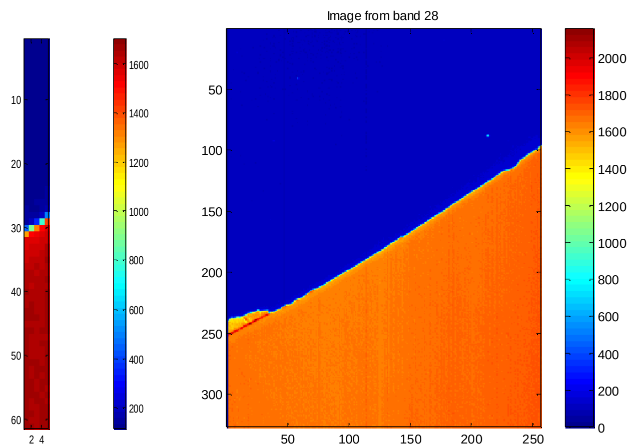

Figure 1: Ross Ice Shelf Image for MTF Processing

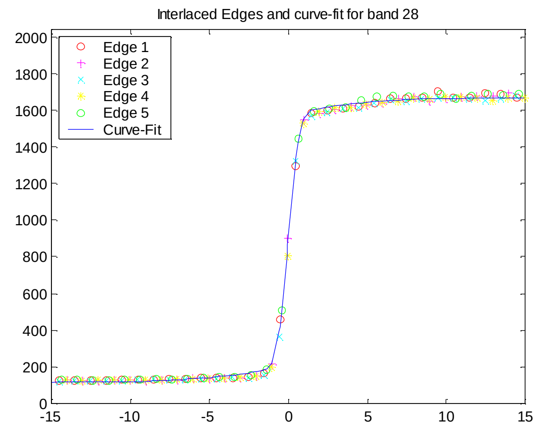

Figure 2: Interlaced ESF and curve-fit

The edge location was calculated for each field pixel scan of the edge. The adjacent field pixels were interlaced to produce the ESF (Fig. 2) based on the edge location of each field pixel. A curve-fit of an error function was then fit to the interlaced ESF. The LSF is directly determined from the curve-fit parameters.

The edge was also processed without a curve-fit by using a band-limited derivative and a Hanning[5] window. The edge from each field pixel was located using a centroid algorithm to produce the interlaced ESF. The interlaced ESF was processed with the derivative filter to produce the LSF. The LSF is then multiplied by a Tukey window[6] that is centered on the LSF to reduce the influence of the noise outside the edge from affecting the MTF. Figure 3 shows the initial edge, LSF from the curve-fit, LSF from the derivative and Tukey window.

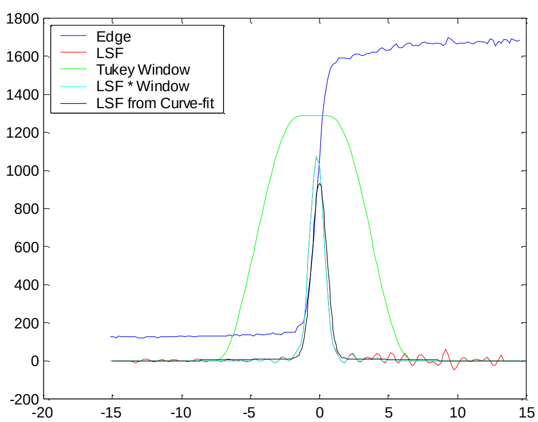

Figure 3: Resulting LSF from ESF

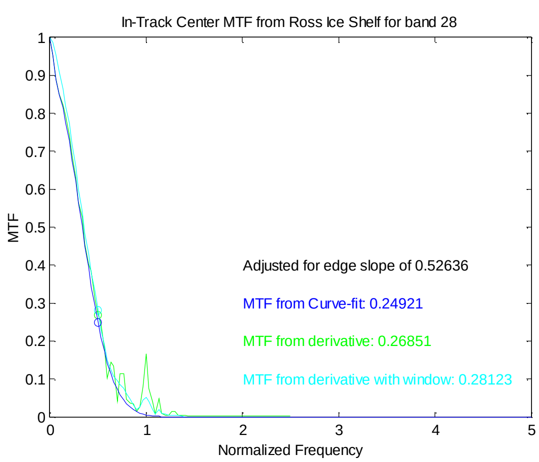

Figure 4: Calculated MTF from LSF

The LSF is processed with Fourier transform to produce the MTF. The MTF is then adjusted for the edge slope. The edge slope in this case is approximately 0.5. This would make a perfect edge (minimal optical LSF) an additional 0.5 pixels wide therefore reducing the MTF. This is analogous to a bridge with a width of 0.5 pixels so the resulting MTF is adjusted by a sinc function. This amount of the edge angle degrades the MTF at Nyquist by 0.02. The resulting MTF for both the curve-fit and derivative method are shown in Figure 4. The MTF at Nyquist from this scene is between 0.25 and 0.28 while the pre-flight measurement was 0.28.

3.2 Bridge Method using Mid-Bay Bridge

The image in Figure 5 is a picture of the Mid-Bay bridge near Eglin AFB and Destin, Florida. The Hyperion image was acquired on December 24, 2000. This image will be used to measure cross-track MTF. The left picture is a close-up of the bridge from band 30 (λ = 0.650 μm). The right image is a color composite from three Hyperion bands (Red = Band 28, Green = Band 21, Blue = Band 16). The angle between the bridge and the spacecraft direction is too small to use consecutive frames so every 5th frame is used.

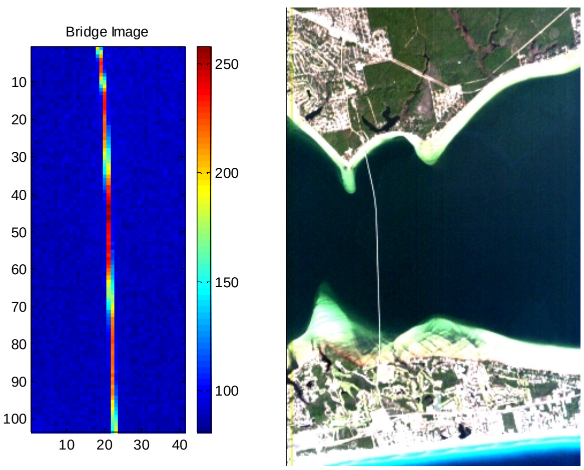

Figure 5: Mid-Bay Bridge for MTF Processing

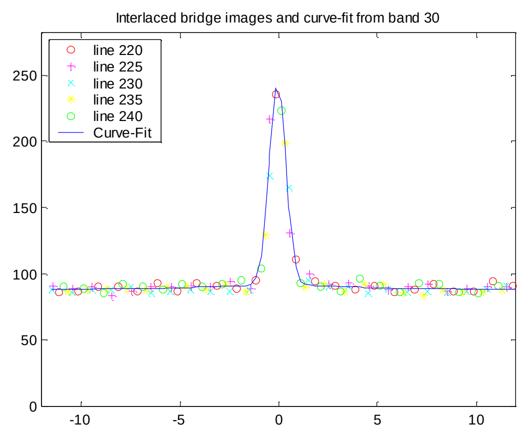

Figure 6: Interlaced LSF and Curve-fit

The frames are processed to determine the location of the bridge. This allows the frames to be interlaced to completely describe the LSF. The LSF is then processed with a curve-fit to a double Gaussian. In Figure 6 the curve-fit is shown with the interlaced frames.

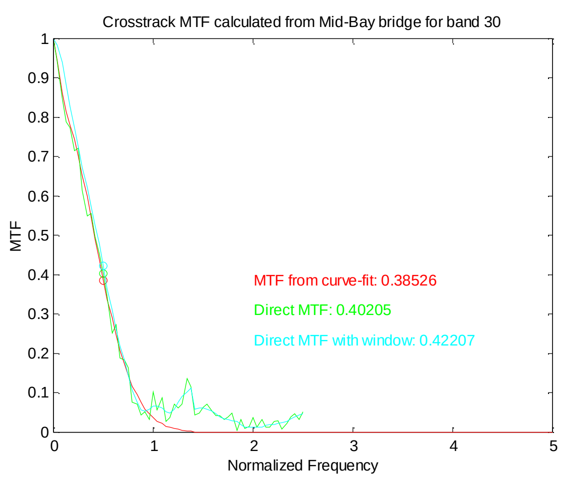

Figure 7: Calculated MTF from LSF

The LSF is processed with a Fourier transform and adjusted by the bridge width to determine the MTF. The bridge width is 13.02 meters which adjusts the MTF by only 0.03 at the Nyquist frequency. The MTF is shown in Figure 7. The MTF at Nyquist from this scene is between 0.39 and 0.42 while the pre-flight measured value was 0.42.

4. COMPARISON WITH PRE-FLIGHT MEASUREMENTS

Figure 8 shows the difference between the cross-track MTF between pre-flight and on-orbit measurements. The average difference is 0.042 and the standard deviation is 0.056. Figure 9 shows the difference between the in-track MTF between pre-flight and on-orbit measurements. The average difference is 0.02 and the standard deviation is 0.037.

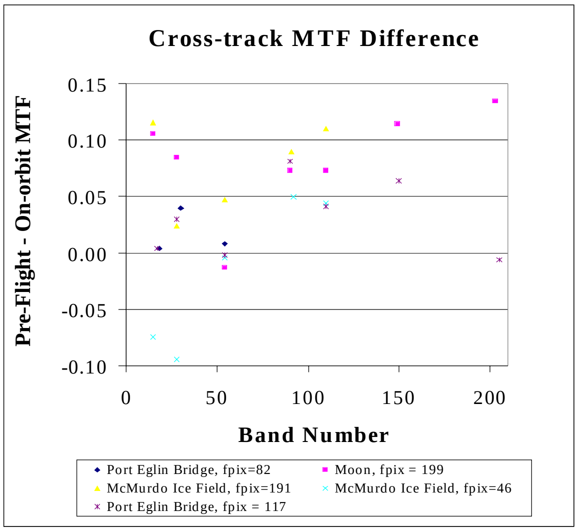

Figure 8: Cross-Track MTF Measurements

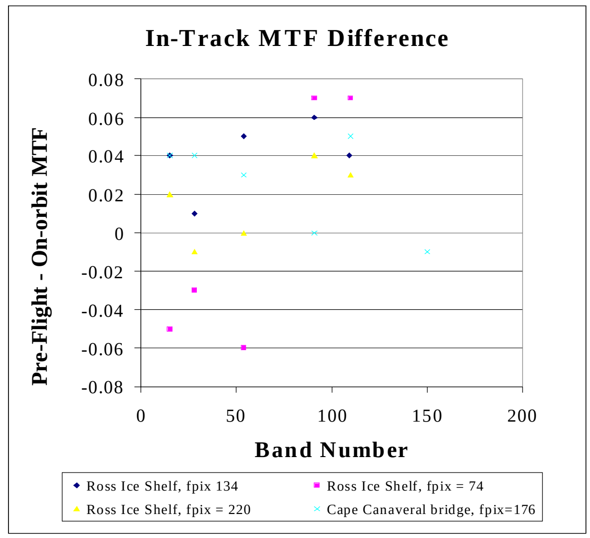

Figure 9: In-Track MTF Measurements

4.1 Edge vs. Bridge Method Comparison

In the VNIR the bridge method and the edge method produce a similar difference between the pre-flight and on-orbit measurements. However in the SWIR the bridge method was significantly closer to the pre-flight measurement. The scenes for the edge method included scenes of the moon and glaciers next to the ocean.

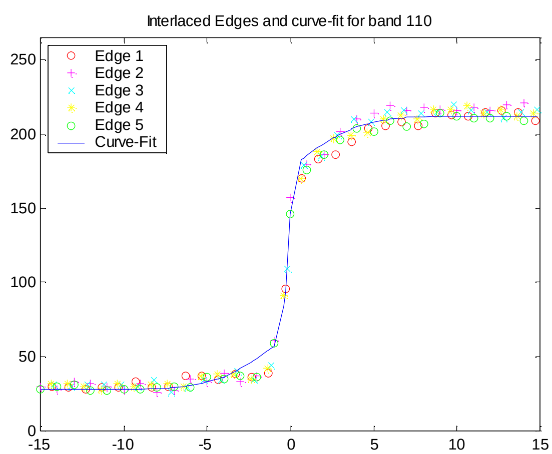

Figure 10: Ross Ice Shelf edge at λ=2.2 μm

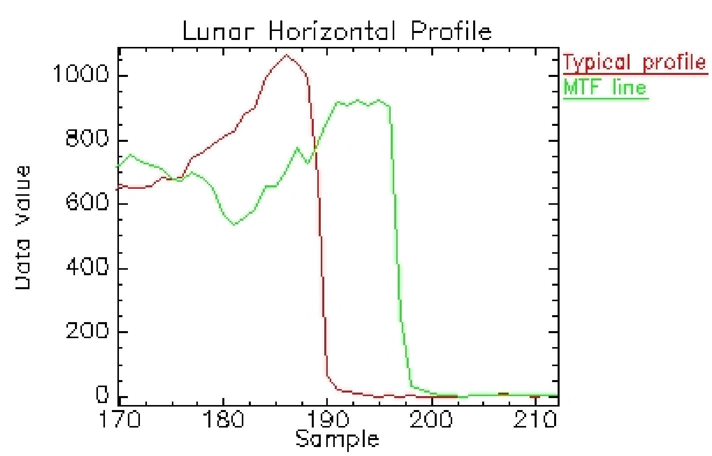

Figure 11: Lunar Profile Comparison

A cross-track profile of the moon is shown in Figure 11. The typical profile had a significant amount of overshoot which causes problems with the MTF algorithm. Fortunately one section of the moon edge was uniform so the scene could be utilized for a MTF measurement. For the glaciers the reflectance has been observed to be reduced near the edge (Figure 10) in the SWIR while the VNIR did not show this behavior (see Figure 2 for a comparison). This edge resulted in a wider LSF and consequently a lower MTF. Glaciers were utilized for in-track and cross-track MTF measurements at several field locations so the data set in the SWIR is biased with the on-orbit measurement being significantly below the pre-flight measurement. Fortunately bridge scenes were available for a cross-track and in-track MTF measurement that have provided results much closer to the pre-flight measurements. A bridge near Cape Canaveral for the in-track measurement provided results close to the pre-flight measurements over both the VNIR and SWIR spectrum. This double structure bridge is close to 1 GSD wide causing the processing adjustment for the bridge image to be a factor of 2 at Nyquist. For the cross-track MTF measurement the bridge near Eglin AFB resulted in values much closer to the pre-flight measurements than the edge method.

5. MTF MEASUREMENT USING SPOTLIGHTS

MTF has previously been measured using a spotlight[7] and an array of point sources[8]. This measurement utilizes an array of spotlights. This method is also useful for measuring spatial and spectral accuracy in a hyperspectral imager. In this two phased experiment an initial test was performed early in the EO-1 mission (Dec 10, 2000) in preparation for a full test in January. The full test utilized a spotlight array similar to the point source array in reference 8 except this array used a 3 x 3 instead at a spacing of 5.33 GSD instead of a 4 x 4 pattern at 5.25 GSD. This array produces a scene that can be used for an in-track and cross-track MTF measurement. Unfortunately the January experiment was cancelled due to poor weather. The initial test used only 3 spotlights in the 3 x 3 array which only allows a calculation of cross-track MTF. This scene was captured by the Advanced Land Imager[9] (ALI) but not Hyperion due to its smaller field of view. The ALI multi-spectral bands have the same GSD as Hyperion so these bands were used to demonstrate the technique.

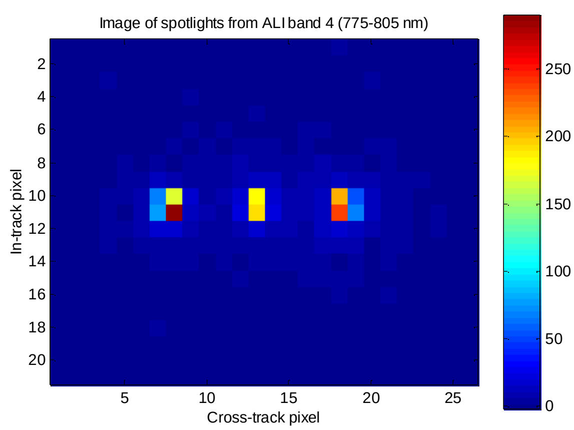

Figure 12: Spotlight Image from ALI band 4 (775-805 nm)

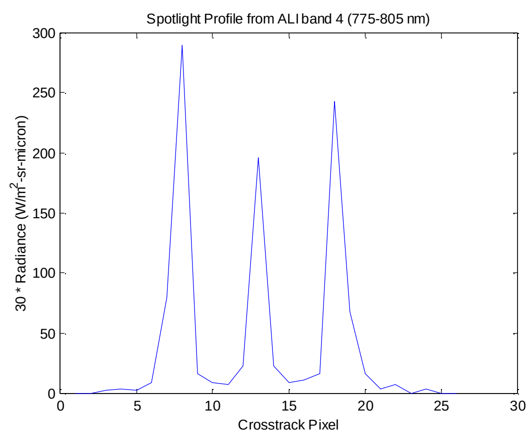

Figure 13: Spotlight Profile from ALI band 4

Figures 12 and 13 are the image and profile from ALI band 4. The weather conditions during the scene acquisition were high clouds. This produced a PSF that was wider than the pre-flight measured PSF. The interlaced PSF and resulting cross-track MTF is shown in Figure 14 and 15. The pre-flight measured MTF value for ALI band 4 was 0.521. At this point in the EO-1 mission the ALI focal plane was contaminated which has been shown to degrade the measured MTF. Therefore the measurement results are consistent with the pre-flight values and degradation due to weather and contamination. Consistent results were also obtained for multi-spectral bands 4'(845-890 nm), 5'(1200-1300 nm), 5(1550-1750 nm) and 7(2080-2350 nm). The bands with wavelengths below band 4 incurred substantial scatter from the clouds resulting in an unreliable MTF value. The ALI focal plane contamination has been removed since this test and the instrument performance has been shown to agree with pre-flight measurements.

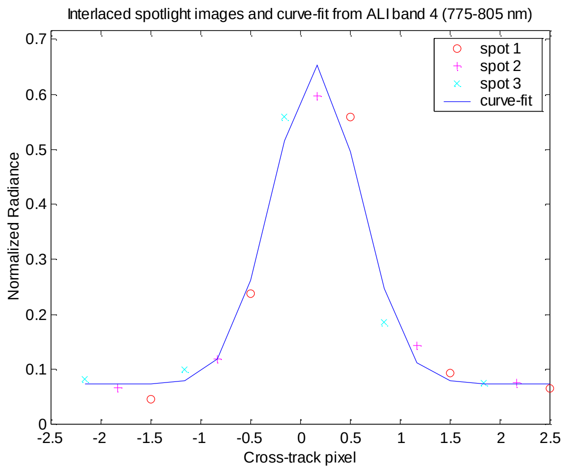

Figure 14: Interlaced spotlight image from ALI band 4

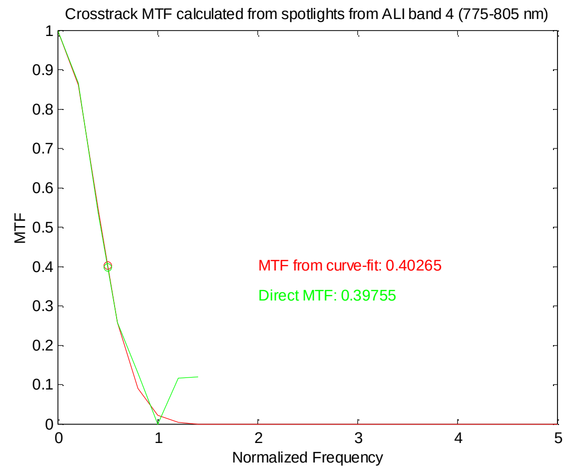

Figure 15: Cross-track MTF from ALI band 4

6. CONCLUSIONS

This paper has described the MTF measurements that have been performed using on-orbit imaging from the Hyperion imaging spectrometer. The MTF was calculated for both edge and bridge objects with reasonable agreement with the pre-flight measurements. Bridge scenes produced excellent correlation with the pre-flight measurements while the edge scenes offered challenges for continued algorithm development. Based on the average difference between the pre-flight and on-orbit MTF measurements there has not been significant change in the Hyperion optical performance due to the launch or operational environment. Consistent MTF measurements of ALI have been obtained using a 3 spotlight scene.

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